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Aliens in Transylvania: risk maps of invasive alien plant species in Central Romania

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Abstract

Using the MAXENT algorithm, we developed risk maps for eight invasive plant species in southern Transylvania, Romania, a region undergoing drastic land-use changes. Our findings show that invasion risk increased with landscape heterogeneity. Roads and agricultural areas were most prone to invasion, whereas forests were least at risk.

Keywords

Erigeron annuus, MAXENT, *Robinia pseudoacacia*, Romania, *Solidago canadensis*, *Xanthium strumarium*

Introduction

Species distribution models are a useful tool in biological invasion risk management (Jiménez-Valverde et al. 2011). They allow a rapid assessment of the distribution of alien species, which may serve to identify areas of high invasibility and to understand the mechanisms behind the establishment and spread of alien species (Zimmermann et al. 2011).

We focused our study on southern Transylvania, in Central Romania, where temporary or permanent abandonment of agricultural land is common. Knowledge on the introduction history of invasive plant species and their current distribution in this region is largely missing, although several common alien plant species are among the world's 100 worst invaders (DAISIE 2013; GISD 2013). To address this knowledge gap, we aimed to identify predictors of the distribution of eight highly invasive species.

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Methods

Study area

Our study area comprised an area of 7,440 km^2 (Fig. 1). It is a heterogeneous, hilly, rural landscape, at elevations from 230 to 1100 m, and characterized by a mosaic of different land cover types supporting high farmland biodiversity (Loos et al. 2014). Small-scale semi-subsistence farming with little use of machinery or agrochemicals, as well as extensively used hay meadows and grasslands are typical for the region. The small-scale mosaic pattern of different land cover types prevails throughout the study area, although the North-West has a relatively higher percentage of arable land, the South has a relatively higher percentage of pastures, and the central part a higher percentage of forests (Hanspach et al. 2014). Like many other parts of Eastern Europe, Romania has experienced drastic socio-economic changes, with the collapse of the

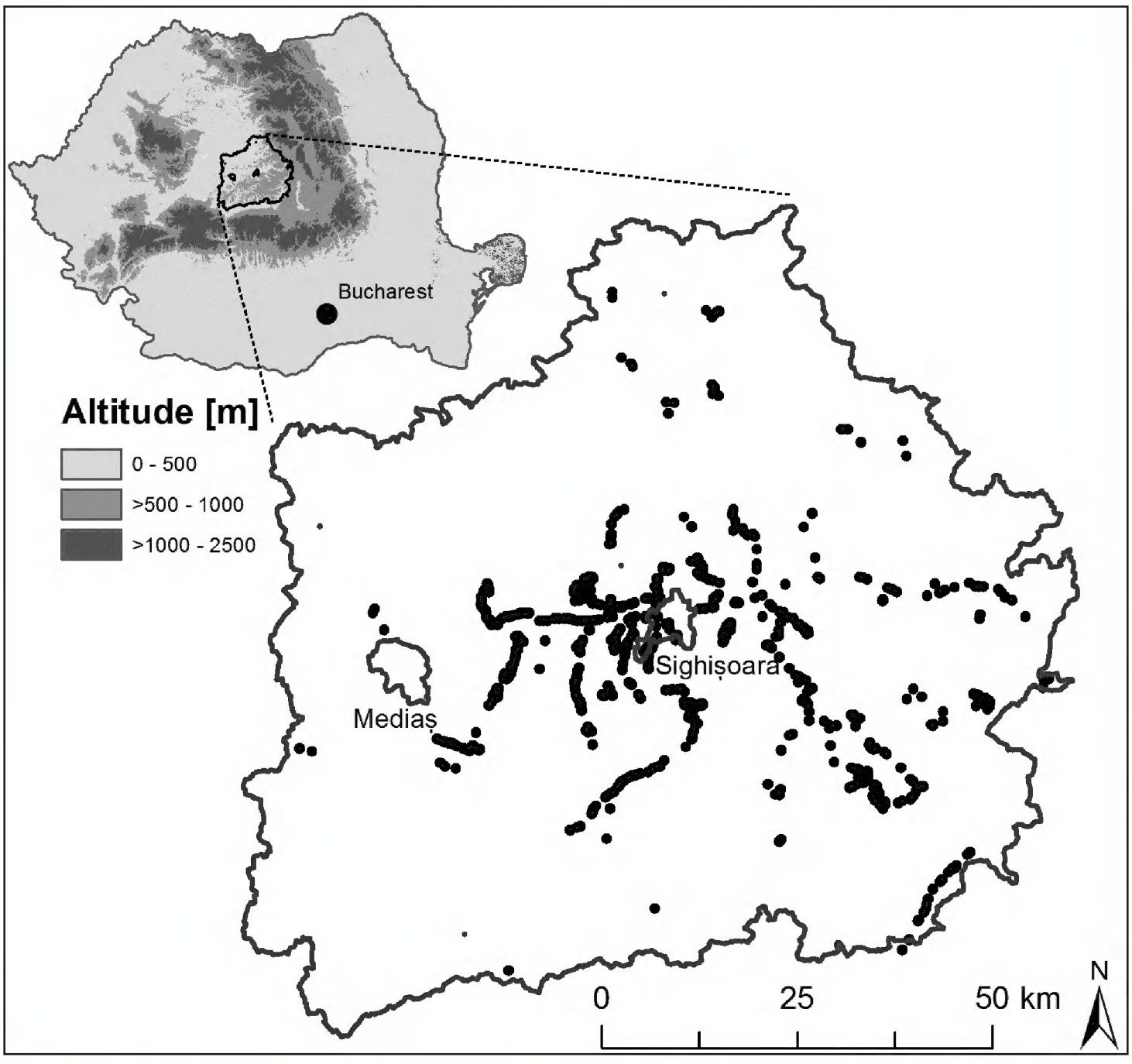

Figure 1. Location of our study area in Romania. Inside the enlarged map of our study area the cities Mediaș and Sighișoara are outlined and black points represent the presence points of all eight study species.

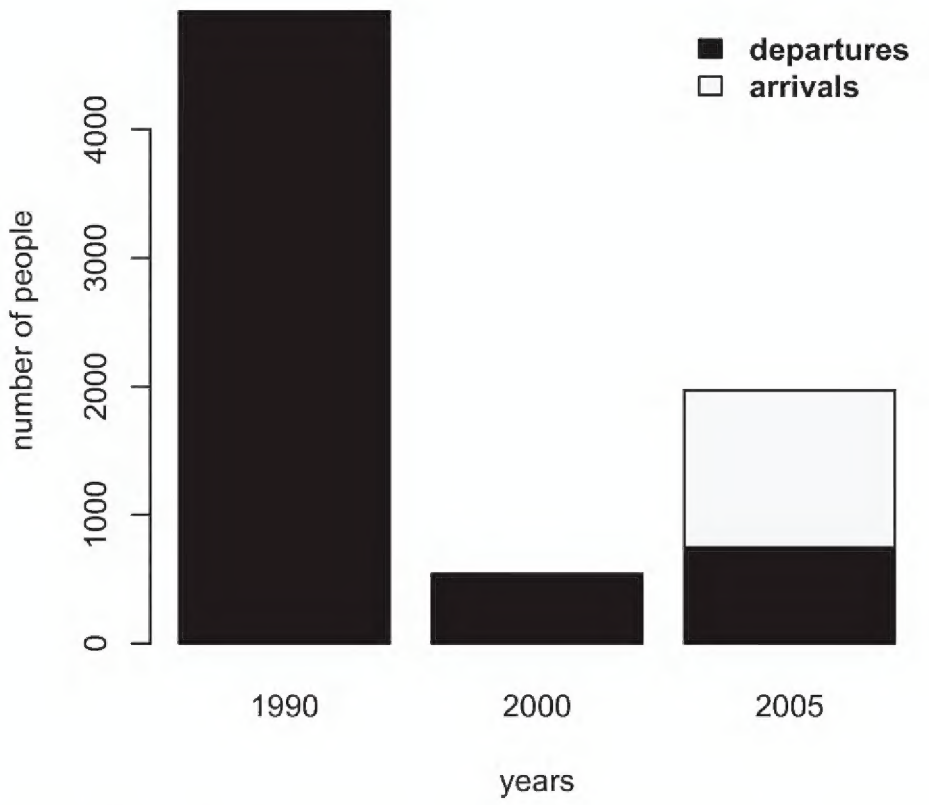

Figure 2. Population census data from 1990, 2000 and 2005 for a subsample of 22 communes across the study area. One commune typically includes four villages. In Romania the communist regime and its collapse in 1989 triggered mass emigration from these areas.

communist regime in 1989, and its accession to the European Union in 2007 (Kuemmerle et al. 2009). Among other changes, the communist regime and its collapse triggered mass emigration from some areas, resulting in widespread farmland abandonment (Fig. 2).

Sampling

In summer 2013, we mapped presences of eight prominent alien plant species across the study area using a handheld global positioning system (Table 1, see also Suppl. material 1). Our sampling covered a large variety of landscape elements within 50 km of the town of Sighișoara (Fig. 1). In each local valley, we undertook at least two extended survey walks that lasted between 30 and 180 minutes. We sampled along roads, but also tracked species off-road, by walking towards the top of the hills bordering a given valley (see Suppl. material 2 for details). Furthermore, we took sample points whenever we observed an invasive species during our other field activities. For *Robinia pseudoacacia* we did not record planted trees, but only naturally dispersed individuals. We did not measure the distance to the next adult tree, but the minimum distance was approx. 100 m and for most recordings adult trees were not in sight. We also included vegetation sampling data from 2012, which was based on a randomized stratified design. The minimum distance between sampling points was 30 m. In combination, our sampling approach covered a wide range of environments across the study area.

Table 1. Overview of study species and number of sampling points (N Am = North America).

Species	Family	Common name	Life strategy	Origin	Reproduction/dispersal	Presence points
Amaranthus retroflexus L.	Amaranthaceae	Redroot amaranth	annual herb ~1 m	N Am	monoecious, wind pollinated, dispersed by wind, water and animals	45
Asclepias syriaca L.	Apocynaceae	Common milkweed	perennial herb ~1–2 m	N Am	insect pollinated, seeds wind dispersed, and vegetative reproduction (rhizomes)	65
Conyza canadensis (L.) Cronquist	Asteraceae	Canadian horseweed	annual herb ~1 m	N Am	insect pollinated, self- and cross-fertilization, seeds wind dispersed	35
Erigeron annuus (L.) Pers.	Asteraceae	Annual fleabane	annual herb ~1 m	N Am	insect pollinated, self- and cross-fertilization, winged achenes dispersed by wind and animals	475
Fallopia japonica (Houtt.) Ronse Decr.	Polygonaceae	Japanese knotweed	perennial herb ~3 m	Asia	insect pollinated, dioecious, winged achenes dispersed by wind, water, animals, and reproduces vigorously by rhizomes	69
Robinia pseudoacacia L.	Fabaceae	Black locust	deciduous tree ~30 m	N Am	insect pollinated, seeds wind dispersed, reproduces vigorously by root suckering and stump sprouting	264
Solidago canadensis L.	Asteraceae	Canadian goldenrod	perennial herb ~2.5 m	N Am	insect pollinated out-crossing, wind dispersed achene with pappus, and vegetative reproduction (rhizomes)	298
Xanthium strumarium L.	Asteraceae	Common cocklebur	annual herb ~1 m	N Am	wind-pollinated, monoecious, self- and cross- fertilization, apomixis, seeds dispersed by animals and water	236

Analysis

We derived invasion risk maps for each species individually. To this end, we applied the Maximum Entropy algorithm (MAXENT), which is based on presence only data to map the likely current distribution for each species in our study area (Phillips et al. 2006; Elith et al. 2011; Merow et al. 2013). Our approach to model the likely current distribution based on presence only data is in line with our assumption that the expansion of our species has not yet reached equilibrium, making the use of observed absences misleading (Jiménez-Valverde et al. 2011). Clamping was activated as well as random seed, and we made an internal validation with 50 replicates and 20 % random test percentage. Predictors encompassed information on the topography, land use and potential distribution corridors (Table 2). Slope and terrain ruggedness (the variation in altitude) did not improve any of the models. Our final models therefore included four predictors (road and village distance, heterogeneity, and land cover classes). Each of these predictors was re-sampled to a cell size of 30 x 30 m within ArcGIS, which

Table 2. Predictors for the MAXENT model. All predictors have a 30 x 30 m resolution. (h.s. = habitat suitability).

Predictor	Description	Relative importance in the MAXENT model
Road distance	minimum distance to the closest road	18 to < 40 % (*A. retroflexus, A. syriaca, C. canadensis*) 45–48 % (*E. annuus, R. pseudoacacia, S. canadensis*) >50%–56% (*F. japonica, X. strumarium*) for all species h.s. high with decreasing distance
Village distance	minimum distance to the closest village	15 % (*S. canadensis*) high h.s. at 3-4 km for remaining species values <10%
Heterogeneity (CNES 2007, Distribution Spot Image SA)	variation in the panchromatic channel of SPOT 5 satellite imagery	>20 %–35% (*A. syriaca, C. canadensis, E. annuus, F. japonica, S. canadensis, X. strumarium*) >40%–46% (*A. retroflexus, R. pseudoacacia*) for all species h.s. high with increasing heterogeneity
Corine land cover classes (Corine 2006 Land Cover Map, EEA (2006) Corine land cover 2000 -- A seamless vector database (European Environment Agency, Copenhagen)	(1) broad leaved forest (2) coniferous and mixed forest (3) water (4) inland marshes (5) natural areas (sparsely vegetated, bare rocks, natural grasslands) (6) transitional woodland-shrub habitats (7) artificial surfaces (8) agriculture (9) pasture (10) Land principally occupied by agriculture with significant areas of natural vegetation	15 % (*X. strumarium* high h.s. for class 8) 22% (*A. retroflexus* high h.s. for class 4) 23 % (*A. syriaca* high h.s. for classes 8, 9) 35% (*C. canadensis* high h.s. for classes 8, 10) for remaining species values <15 %

thus equals the resolution of our risk maps. To calculate the potential areas suitable for each species a threshold rule was applied to convert continuous suitability surfaces into binary outputs. We selected the threshold "maximum training sensitivity plus specificity logistic threshold", which focuses on the correct classification of presences and background points (Jiménez-Valverde and Lobo 2007).

For each grid cell, we then calculated the mean probability of occurrence over all eight species. This resulted in a map of general invasion risk for the study area, referred to "the invasibility map" hereafter.

Results

Single distribution models of the eight study species all had high discrimination performances with AUC values ranging from 0.8 to 0.9 (Elith 2002). Standard deviation of the output grids showed no signs of autocorrelation (see also Suppl. material 2). Road distance and heterogeneity were the most important predictors (Table 2). Corine land cover classes substantially improved the MAXENT model of three species, with agricultural areas, pastures and land principally occupied by agriculture with significant areas of natural vegetation, having the highest risk of invasion. Forest was at least risk of being

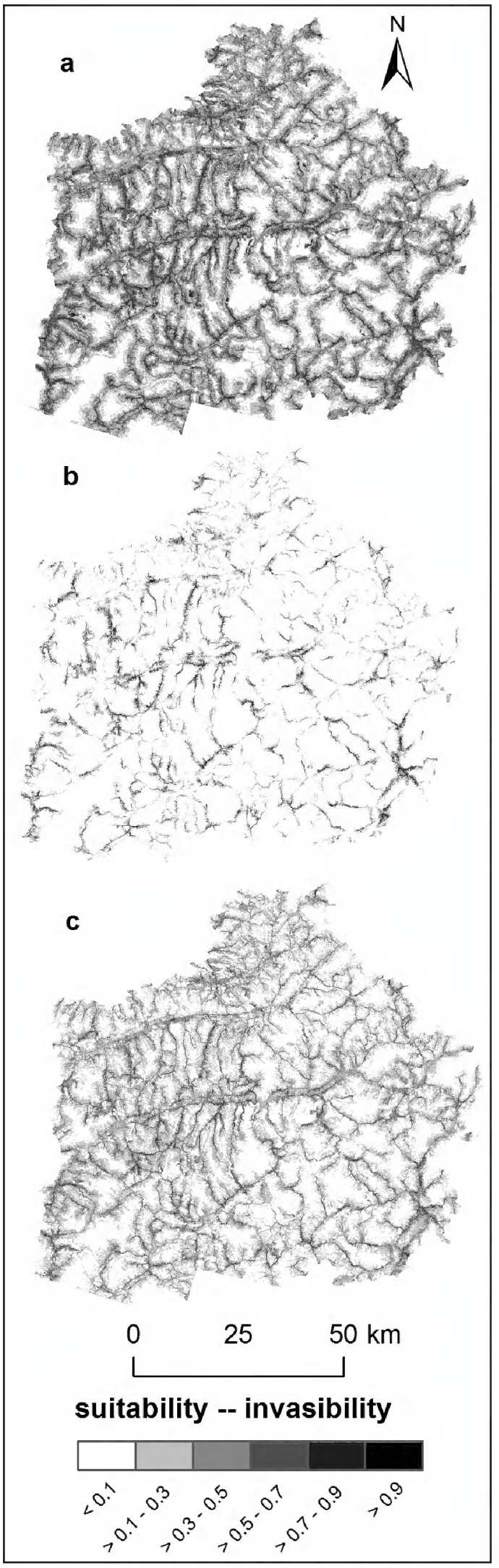

Figure 3. The likely current distribution for **a** *Erigeron annuus* and **b** *Asclepias syriaca* in our study area. **c** Shows the invasibility, calculated as the mean probability of occurrence over all eight study species.

invaded. With 31 % potential habitat, *Erigeron annuus* has the largest potential distribution and with 8 %, *Asclepias syriaca* had the lowest (Fig. 3 a, b). Risk maps of all species show a high invasibility of distribution corridors such as roads and rivers (see Suppl. material 3). The overall invasibility map therefore shows a network structure with the highest invasibility close to distribution corridors stretching across the whole study area (Fig. 3c). However, the invasibility was highest in heterogeneous areas, which is where it also reached furthest away from roads.

Discussion

Our risk maps show that the eight invaders considered have great potential to further expand their distributions. All except for one study species are wind dispersed, which is an effective long distance dispersal method (Cain et al. 2000). Roads serve as invasion corridors, enabling the species establishment inside disturbed road margins (Birdsall et al. 2011). Environments at greatest risk of invasion away from roads appeared to be heterogeneous agricultural areas. Landscape heterogeneity is beneficial for native species in farming landscapes, because it offers a greater variety of habitats (Fischer and Lindenmayer 2007). However, invasive species also appear to benefit from this variety. A positive correlation of native and invasive plant species richness in relation to landscape heterogeneity was also shown for the Rocky Mountain National Park in the USA (120-960 m radius scale; Kumar et al. 2006), for rural and urban areas in Germany (32 km^2 scale; Deutschewitz et al. 2003), as well as for rural areas and woodlands in Catalonia (100 km^2 scale; Bartomeus et al. 2012). Furthermore, heterogeneous landscapes offer more edge environments which are subject to higher levels of propagule pressure and disturbance, and therefore a higher abundance of invasive plant species (Vilà and Ibáñez 2011). Like many invasive species, our study species are adapted to disturbance through their short life cycles, rapid germination, persistent seed banks, or vegetative reproduction (Rejmánek and Richardson 1996; Kolar and Lodge 2001).

We observed that areas with a high heterogeneity often coincides with areas that experienced the most widespread emigration following the collapse of communism. Socio-economic effects at regional or local scales are rarely considered in invasion science (Vilà and Pujadas 2001, Guo et al. 2012). This is a potentially important oversight. For example, farmland abandonment and land-use change can facilitate high abundances of alien plant species (Hobbs 2000; Cramer et al. 2008). Decades of cultivation may deprive native seed banks and altered soil conditions may no longer be suitable for native species (Cramer et al. 2008). In comparison to native species, species new to this region may possess traits that make them better colonizers of abandoned fields. They benefit from increased human mediated propagule pressure (propagule bias), are often stronger competitors (enemy release, novel weapons), and once established may further transform their environment, making it even less suitable for native species – thereby creating self-perpetuating

alien monocultures (Catford et al. 2012). Our study area continues to undergo socio-economic changes. With our main project ("Fostering sustainable development in Eastern Europe" http://peisajesustenabile.wordpress.com/) we aim to provide leverage points for enabling sustainable land use practices. Based on the results of this study we recommend to preserve the remaining intact forests, which seem to be least in risk of invasions and to further investigate the role of land abandonment and land use change in our study area.

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Supplementary material 1

Table of species localities.

Authors: Heike Zimmermann, Jacqueline Loos, Henrik von Wehrden, Joern Fischer

Data type: (measurement/occurence/multimedia/etc.)

Explanation note: Table of all species localities (latitude and longitude in decimal degrees, WGS 84).

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Supplementary material 2

Check for sampling bias.

Authors: Heike Zimmermann, Jacqueline Loos, Henrik von Wehrden, Joern Fischer

Data type: (measurement/occurence/multimedia/etc.)

Explanation note: We checked our dataset for sampling bias, that is the distribution of presence points (N = 1484) at different road distances.

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Supplementary material 3

Risk maps for all eight study species.

Authors: Heike Zimmermann, Jacqueline Loos, Henrik von Wehrden, Joern Fischer

Data type: (measurement/occurence/multimedia/etc.)

Explanation note: Risk maps for all eight study species derived from the MAXENT model.

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